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1/1 PLUSPAT - (C) QUESTEL-ORBIT  
 PN - US5528482 A 19960618 [US5528482]  
 TI - (A) Low loss synchronous rectifier for application to clamped-mode power converters  
 PA - (A) AT & T CORP (US)  
 IN - (A) ROZMAN ALLEN F (US)  
 AP - US22502794 19940408 [1994US-0225027]  
 PR - US22502794 19940408 [1994US-0225027]  
 - US5491893 19930429 [1993US-0054918]  
 IC - (A) H02M-007/217  
 EC - H02M-003/335S  
 - H02M-003/335S2S  
 - H02M-007/217  
 PCL - ORIGINAL (O) : 363021060; CROSS-REFERENCE (X) : 327309000 363020000 363089000  
 DT - Corresponding document  
 CT - US5066900; US5126931; US5303138  
 - Principles of Solid-State Power Conversion, Tarter, 1st Ed, (1985), pp. 544-547.

"Current-Controlled Synchronous Rectrification" by B. Acker; C. R. Sullivan S. R. Sanders IEEE pp. 185-191, May 1994.

"High Efficiency DC--DC Converter" by I. D. Jitaru; G. Cocina. IEEE, pp. 638-644. May 1994.

STG - (A) United States patent  
 AB - A synchronous rectifier for use with a clamped-mode power converter uses in one embodiment a hybrid rectifier with a MOSFET rectifying device active in one first cyclic interval of the conduction/nonconduction sequence of the power switch and a second rectifying device embodied in one illustrative embodiment as a low voltage bipolar diode rectifying device active during an alternative interval to the first conduction/nonconduction interval. The gate drive to the MOSFET device is continuous at a constant level for substantially all of the second interval which enhances efficiency of the rectifier. The bipolar rectifier device may also be embodied as a MOSFET device. The subject rectifier may be used in both forward and flyback power converters.

1/1 LGST - (C) LEGSTAT  
 PN - US 5528482 [US5528482]  
 AP - US 225027/94 19940408 [1994US-0225027]  
 DT - US-P  
 ACT - 19940408 US/AE-A  
 APPLICATION DATA (PATENT)  
 {US 225027/94 19940408 [1994US-0225027]]  
 - 19940613 US/AS02  
 ASSIGNMENT OF ASSIGNOR'S INTEREST  
 AT&T CORP. 32 AVENUE OF THE AMERICAS NEW YORK, NY 10013-2412 \* ROZMAN, ALLEN FRANK : 19940607  
 - 19960618 US/A  
 PATENT  
 - 19980721 US/RF  
 REISSUE APPLICATION FILED  
 980313  
 - 19991228 US/RF

REISSUE APPLICATION FILED

19991027

UP - 2000-04

1/1 CRXX - (C) CLAIMS/RRX

AN - 2731188

PN - 5,528,482 A 19960618 [US5528482]

PA - AT&T Corp

PT - E (Electrical)

ACT - 19980313 REISSUE REQUESTED

Issue Date of O.G.: 19980721

Reissue Request Number: 09/039106

Examination Group responsible for Reissue process: 2111

Reissue Patent Number: USRE36571

- 19991027 REISSUE REQUESTED

Issue Date of O.G.: 19991228

Reissue Request Number: 09/429692

Examination Group responsible for Reissue process: 2838

UP - 1999-00

UACT- 1999-12-28

1/2 PAST - (C) PAST

AN - 200007-001118

PN - 5528482 A [US5528482]

DT - A (UTILITY)

OG - 2000-02-15

CO - RE

ACT - REISSUE PATENT

SH - REISSUE PATENT

RL - USRE36571

2/2 PAST - (C) PAST

AN - 199829-001042

PN - 5528482 A [US5528482]

DT - A (UTILITY)

OG - 1998-07-21

CO - REA

ACT - REISSUE APPLICATION FILED

SH - REISSUE APPLICATION FILED

4/39/1

DIALOG(R) File 345:Inpadoc/Fam.& Legal Stat  
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11722092

Basic Patent (No,Kind,Date): US 5303138 A 19940412 <No. of Patents: 010>

Patent Family:

Patent No	Kind	Date	Applic No	Kind	Date	
EP 1052763	A1	20001115	EP 2000108230	A	19940420	
EP 622891	A2	19941102	EP 94302791	A	19940420	
EP 622891	A3	19950111	EP 94302791	A	19940420	
JP 6327243	A2	19941125	JP 94113420	A	19940502	
JP 2758137	B2	19980528	JP 94113420	A	19940502	
US 5303138	A	19940412	US 54918	A	19930429	(BASIC)
US 5528482	A	19960618	US 225027	A	19940408	
US 5625541	A	19970429	US 503684	A	19950718	
US 5872705	A	19990216	US 704056	A	19960828	
US RE36571	E	20000215	US 39106	A	19980313	

Priority Data (No,Kind,Date):

EP 94302791 A3 19940420  
US 54918 A 19930429  
US 225027 A 19940408  
US 54918 A2 19930429  
US 503684 A 19950718  
US 225027 A2 19940408  
US 704056 A 19960828  
US 516423 B1 19950817  
US 225027 A1 19940408  
US 39106 A 19980313  
US 225027 A5 19940408  
US 54918 A1 19930429

PATENT FAMILY:

EUROPEAN PATENT OFFICE (EP)

Patent (No,Kind,Date): EP 1052763 A1 20001115

LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER  
CONVERTERS (English; French; German)

Patent Assignee: AT & T CORP (US)

Author (Inventor): ROZMAN ALLEN FRANK (US)

Priority (No,Kind,Date): EP 94302791 A3 19940420; US 54918 A  
19930429

Applic (No,Kind,Date): EP 2000108230 A 19940420

Designated States: (National) DE; FR; GB

IPC: \* H02M-003/335

Derwent WPI Acc No: \* G 94-117846; G 96-300133; G 97-258430; G  
99-166852

Language of Document: English

Patent (No,Kind,Date): EP 622891 A2 19941102

LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER  
CONVERTERS. (English; French; German)

Patent Assignee: AT & T CORP (US)

Author (Inventor): ROZMAN ALLEN FRANK (US)

Priority (No,Kind,Date): US 54918 A 19930429

Applic (No,Kind,Date): EP 94302791 A 19940420

Designated States: (National) DE; FR; GB

IPC: \* H02M-007/217; H02M-003/335

Derwent WPI Acc No: \* G 94-117846; G 96-300133; G 97-258430; G

99-166852

Language of Document: English

Patent (No,Kind,Date): EP 622891 A3 19950111

LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS. (English; French; German)

Patent Assignee: AT & T CORP (US)

Author (Inventor): ROZMAN ALLEN FRANK (US)

Priority (No,Kind,Date): US 54918 A 19930429

Applic (No,Kind,Date): EP 94302791 A 19940420

Designated States: (National) DE; FR; GB

IPC: \* H02M-007/217; H02M-003/335

Derwent WPI Acc No: \* G 94-117846; G 96-300133; G 97-258430; G

99-166852

Language of Document: English

#### EUROPEAN PATENT OFFICE (EP)

Legal Status (No,Type,Date,Code,Text):

EP 622891 P 19930429 EP AA PRIORITY (PATENT APPLICATION) (PRIORITAET (PATENTANMELDUNG))

EP 622891 P 19940420 EP AE EP-APPLICATION (EUROPAEISCHE ANMELDUNG)

EP 622891 P 19941102 EP AK DESIGNATED CONTRACTING STATES IN AN APPLICATION WITHOUT SEARCH REPORT (IN EINER ANMELDUNG OHNE RECHERCHENBERICHT BENANNT VERTRAGSSTAATEN)

EP 622891 P 19941102 EP A2 PUBLICATION OF APPLICATION WITHOUT SEARCH REPORT (VEROEFFENTLICHUNG DER ANMELDUNG OHNE RECHERCHENBERICHT)

EP 622891 P 19950111 EP AK DESIGNATED CONTRACTING STATES IN A SEARCH REPORT (IN EINEM RECHERCHENBERICHT BENANNT VERTRAGSSTAATEN)

EP 622891 P 19950111 EP A3 SEPARATE PUBLICATION OF THE SEARCH REPORT (ART. 93) (GESONDERTE VEROEFFENTLICHUNG DES RECHERCHENBERICHTS (ART. 93))

EP 622891 P 19950830 EP 17P REQUEST FOR EXAMINATION FILED (PRUEFUNGSANTRAG GESTELLT) 950630

EP 622891 P 19970423 EP 17Q FIRST EXAMINATION REPORT (ERSTER PRUEFUNGSBESCHEID) 970307

EP 622891 P 20000607 EP RAHF DIVISIONAL APPLICATION (ART 76) IN: (CORRECTION) (TEILANMELDUNG (ART. 76) IN: (KORR.))

EP 622891 P 20001115 EP AH DIVISIONAL APPLICATION (ART. 76) IN: (TEILANMELDUNG (ART. 76) IN:)

EP 1052763 P 19930429 EP AA PRIORITY (PATENT APPLICATION) (PRIORITAET (PATENTANMELDUNG))

		US 54918 A 19930429
EP 1052763	P	19940420 EP AA DIVIDED OUT OF (AUSSCHIEDUNG AUS)
		EP 94302791 A3 19940420
EP 1052763	P	19940420 EP AE EP-APPLICATION (EUROPAEISCHE ANMELDUNG)
		EP 2000108230 A 19940420
EP 1052763	P	20001115 EP AC DIVISIONAL APPLICATION (ART. 76) OF: (TEILANMELDUNG (ART. 76) AUS:)
		EP 622891 P
EP 1052763	P	20001115 EP AK DESIGNATED CONTRACTING STATES IN AN APPLICATION WITH SEARCH REPORT: (IN EINER ANMELDUNG BENANNT VERTRAGSSTAATEN)
		DE FR GB
EP 1052763	P	20001115 EP A1 PUBLICATION OF APPLICATION WITH SEARCH REPORT (VEROEFFENTLICHUNG DER ANMELDUNG MIT RECHERCHENBERICHT)
EP 1052763	P	20001115 EP 17P REQUEST FOR EXAMINATION FILED (PRUEFUNGSANTRAG GESTELLT) 20000426

#### JAPAN (JP)

Patent (No,Kind,Date): JP 6327243 A2 19941125  
 POWER CONVERTER (English)  
 Patent Assignee: AMERICAN TELEPHONE & TELEGRAPH  
 Author (Inventor): AREN FURANKU ROZUMAN  
 Priority (No,Kind,Date): US 54918 A 19930429  
 Applic (No,Kind,Date): JP 94113420 A 19940502  
 IPC: \* H02M-003/28  
 Language of Document: Japanese  
 Patent (No,Kind,Date): JP 2758137 B2 19980528  
 Patent Assignee: EI TEI ANDO TEI CORP  
 Author (Inventor): AREN FURANKU ROZUMAN  
 Priority (No,Kind,Date): US 54918 A 19930429  
 Applic (No,Kind,Date): JP 94113420 A 19940502  
 IPC: \* H02M-003/28  
 Language of Document: Japanese

#### UNITED STATES OF AMERICA (US)

Patent (No,Kind,Date): US 5303138 A 19940412  
 LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER  
 CONVERTERS (English)  
 Patent Assignee: AT & T BELL LAB (US)  
 Author (Inventor): ROZMAN ALLEN F (US)  
 Priority (No,Kind,Date): US 54918 A 19930429  
 Applic (No,Kind,Date): US 54918 A 19930429  
 National Class: \* 363021000; 363020000; 363089000; 363097000;  
 363127000  
 IPC: \* H02M-003/335; H02M-007/217  
 Derwent WPI Acc No: ; G 94-117846  
 Language of Document: English  
 Patent (No,Kind,Date): US 5528482 A 19960618  
 LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER  
 CONVERTERS (English)  
 Patent Assignee: AT & T CORP (US)

Author (Inventor): ROZMAN ALLEN F (US)  
 Priority (No,Kind,Date): US 225027 A 19940408; US 54918 A2 19930429  
 Applic (No,Kind,Date): US 225027 A 19940408  
 Addnl Info: 5303138 19940412 Patented  
 National Class: \* 363021000; 363020000; 363089000; 327309000  
 IPC: \*. H02M-007/217  
 Derwent WPI Acc No: \* G 94-117846; G 96-300133; G 97-258430; G 99-166852; G 96-300133  
 Language of Document: English  
 Patent (No,Kind,Date): US 5625541 A 19970429  
 LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS (English)  
 Patent Assignee: LUCENT TECHNOLOGIES INC (US)  
 Author (Inventor): ROZMAN ALLEN F (US)  
 Priority (No,Kind,Date): US 503684 A 19950718; US 225027 A2 19940408; US 54918 A2 19930429  
 Applic (No,Kind,Date): US 503684 A 19950718  
 Addnl Info: 5528482 Patented; 5303138 Patented  
 National Class: \* 363021000; 363020000; 363089000; 363147000; 327309000  
 IPC: \* H02M-007/217; H02M-003/335  
 Derwent WPI Acc No: \* G 94-117846; G 96-300133; G 97-258430; G 99-166852; G 97-258430  
 Language of Document: English  
 Patent (No,Kind,Date): US 5872705 A 19990216  
 LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS (English)  
 Patent Assignee: LUCENT TECHNOLOGIES INC (US)  
 Author (Inventor): LOFTUS JR THOMAS PATRICK (US); ROZMAN ALLEN FRANK (US)  
 Priority (No,Kind,Date): US 704056 A 19960828; US 516423 B1 19950817; US 225027 A1 19940408; US 54918 A2 19930429  
 Applic (No,Kind,Date): US 704056 A 19960828  
 Addnl Info: 5528482 19960618 Patented; 5303138 19940412 Patented  
 National Class: \* 363021000; 363089000; 363097000; 363127000; 363131000  
 IPC: \* H02M-003/335  
 Derwent WPI Acc No: ; G 99-166852  
 Language of Document: English  
 Patent (No,Kind,Date): US RE36571 E 20000215  
 LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS (English)  
 Patent Assignee: LUCENT TECHNOLOGIES INC (US)  
 Author (Inventor): ROZMAN ALLEN FRANK (US)  
 Priority (No,Kind,Date): US 39106 A 19980313; US 225027 A5 19940408; US 54918 A1 19930429  
 Applic (No,Kind,Date): US 39106 A 19980313  
 Addnl Info: 5528482 19960618 Reissue of; 5303138 19940412 Patented  
 National Class: \* 363021000; 363020000; 363089000; 327309000  
 IPC: \* H02M-007/217  
 Derwent WPI Acc No: \* G 94-117846; G 96-300133; G 97-258430; G 99-166852  
 Language of Document: English

UNITED STATES OF AMERICA (US)

Legal Status (No,Type,Date,Code,Text):

US 36571	E	19930429	US AA	PRIORITY
		US 54918	A1	19930429
US 36571	E	19940408	US AA	PRIORITY
		US 225027	A5	19940408
US 36571	E	19980313	US AE	APPLICATION DATA (PATENT)
		(APPL. DATA (PATENT))		
		US 39106	A	19980313
US 36571	E	20000215	US E	REISSUE
US 5303138	P	19930429	US AE	APPLICATION DATA (PATENT)
		(APPL. DATA (PATENT))		
		US 54918	A	19930429
US 5303138	P	19930429	US AS02	ASSIGNMENT OF ASSIGNOR'S
		INTEREST		
		AMERICAN TELEPHONE AND TELEGRAPH COMPANY 37		
		AVENUE OF THE AMERICAS NEW YORK, NY ; ROZMAN,		
		ALLEN, F. : 19930421		
US 5303138	P	19940412	US A	PATENT
US 5528482	P	19930429	US AA	PRIORITY
		US 54918	A2	19930429
US 5528482	P	19940408	US AE	APPLICATION DATA (PATENT)
		(APPL. DATA (PATENT))		
		US 225027	A	19940408
US 5528482	P	19940613	US AS02	ASSIGNMENT OF ASSIGNOR'S
		INTEREST		
		AT&T CORP. 32 AVENUE OF THE AMERICAS NEW		
		YORK, NY 10013-2412 ; ROZMAN, ALLEN FRANK :		
		19940607		
US 5528482	P	19960618	US A	PATENT
US 5528482	P	19980721	US RF	REISSUE APPLICATION FILED
		(REISSUE APPL. FILED)		
		980313		
US 5528482	P	19991228	US RF	REISSUE APPLICATION FILED
		(REISSUE APPL. FILED)		
		19991027		
US 5625541	P	19930429	US AA	PRIORITY
		US 54918	A2	19930429
US 5625541	P	19940408	US AA	PRIORITY
		US 225027	A2	19940408
US 5625541	P	19950718	US AE	APPLICATION DATA (PATENT)
		(APPL. DATA (PATENT))		
		US 503684	A	19950718
US 5625541	P	19950718	US AS02	ASSIGNMENT OF ASSIGNOR'S
		INTEREST		
		AT&T IPM CORPORATION 2333 PONCE DE LEON BLVD.		
		CORAL GABLES, FLORIDA 33134 ; ROZMAN, ALLEN		
		FRANK : 19950711		
US 5625541	P	19970429	US A	PATENT
US 5625541	P	19980428	US CC	CERTIFICATE OF CORRECTION
US 5872705	P	19930429	US AA	PRIORITY
		US 54918	A2	19930429
US 5872705	P	19940408	US AA	PRIORITY
		US 225027	A1	19940408
US 5872705	P	19950817	US AA	PRIORITY
		US 516423	B1	19950817
US 5872705	P	19960828	US AE	APPLICATION DATA (PATENT)
		(APPL. DATA (PATENT))		
		US 704056	A	19960828

US 5872705      P    19961113    US AS02      ASSIGNMENT OF ASSIGNOR'S  
INTEREST  
LUCENT TECHNOLOGIES, INC. P.O. BOX 636 600  
MOUNTAIN AVENUE MURRAY HILL, NEW JERS ;  
ROZMAN, ALLEN FRANK : 19961105  
US 5872705      P    19990216    US A      PATENT

1/1 PLUSPAT - (C) QUESTEL-ORBIT

PN - USRE36571 E 20000215 [USRE36571]  
TI - (E) Low loss synchronous rectifier for application to clamped-mode power converters  
PA - (E) LUCENT TECHNOLOGIES INC (US)  
IN - (E) ROZMAN ALLEN FRANK (US)  
AP - US3910698 19980313 [1998US-0039106]  
PR - US3910698 19980313 [1998US-0039106]  
- US22502794 19940408 [1994US-0225027]  
- US5491893 19930429 [1993US-0054918]  
IC - (E) H02M-007/217  
EC - H02M-003/335S  
- H02M-003/335S2S  
PCL - ORIGINAL (O) : 363021060; CROSS-REFERENCE (X) : 327309000 363020000  
363021140 363089000  
DT - Basic  
CT - US3989995; US4441146; US4618919; US4716514; US4788634; US4809148;  
US4857822; US4870555; US4903189; US4931716; US4959764; US4975821;  
US5066900; US5099406; US5126651; US5126931; US5179512; US5231563;  
US5268830; US5274543; US5282123; US5291382; US5303138; US5353212;  
US5434768; US5535112; US5541828; EP0058400 A2; EP0289196 A2; EP0428377  
A2; EP0474471 A2; EP0508664 A1; SU892614; WO8302858; WO8908347  
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"5.6.1 Using Power MOSFETs as High-Efficiency Synchronous and Bridge  
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"Principles of Solid-State Power Conversion" by Ralph E. Tarter; 1985; pp. 544-547.

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"High Efficiency DC-DC Converter" by I.D. Jitaru, Gicocina, IEEE, pp. 638-644 May 1994.

STG - (E) Reissue

AB - A synchronous rectifier for use with a clamped-mode power converter uses in one embodiment a hybrid rectifier with a MOSFET rectifying device active in one first cyclic interval of the conduction/nonconduction sequence of the power switch and a second rectifying device embodied in one illustrative embodiment as a low voltage bipolar diode rectifying device active during an alternative interval to the first conduction/nonconduction interval. The gate drive to the MOSFET device is continuous at a constant level for substantially all of the second interval which enhances efficiency of the rectifier. The bipolar rectifier device may also be embodied as a MOSFET device. The subject rectifier may be used in both forward and flyback power converters.

UP - 2000-10

1/1 PAST - (C) PAST

AN - 200007-001118

PN - 5528482 A [US5528482]

DT - A (UTILITY)

OG - 2000-02-15

CO - RE

ACT - REISSUE PATENT

SH - REISSUE PATENT

RL - USRE36571

Source: [All Sources](#) : [Area of Law - By Topic](#) : [Patent Law](#) : [Patents](#) : [U.S. Patents](#) : [Reissue Patents](#) Terms: **patno is 36571** ([Edit Search](#))

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*Pat. No. 36571, \****RE 36,571**◆ GET 1st DRAWING SHEET OF 4

Feb. 15, 2000

Low loss synchronous rectifier for application to clamped-mode power converters

**INVENTOR:** Rozman, Allen Frank, Richardson, Texas**ASSIGNEE-AT-ISSUE:** Lucent Technologies Inc., Murray Hill, New Jersey (02)**APPL-NO:** 39,106**FILED:** Mar. 13, 1998**REL-US-DATA:**

Reissue of

Patent No.:	5,528,482
Issued:	Jun. 18, 1996
Appl. No.:	8-225,027
Filed:	Apr. 8, 1994

Continuation of Application No. 8-054,918, Apr. 29, 1993 now patented 5,303,138 Apr. 12, 1994

**INT-CL:** [7] H02M 7#217**US-CL:** 363#21; 363#20; 363#89; 327#309**CL:** 363;327**SEARCH-FLD:** 363#20, 21, 89, 97, 126, 127; 327#309**REF-CITED:****U.S. PATENT DOCUMENTS**

<u>3,989,995</u>	11/1976	*	Peterson	321#2
<u>4,441,146</u>	4/1984	*	Vinciarelli	363#20
<u>4,618,919</u>	10/1986	*	Martin, Jr.	363#21
<u>4,716,514</u>	12/1987	*	Patel	363#127
<u>4,788,634</u>	11/1988	*	Schlecht et al.	363#21
<u>4,809,148</u>	2/1989	*	Barn	363#20

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**Sources**


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re w/1 36571 or re36571 or usre36571 or re  
w/1 36,571 or re36,571 or usre36,571

 **Search**




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 **Suggest Words and Concepts for Entered Terms**

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*Pat. No. 5,528,482, \****5,528,482**◆ GET 1st DRAWING SHEET OF 4

Jun. 18, 1996

Low loss synchronous rectifier for application to clamped-mode power converters

**REISSUE:** This Patent was reissued on Feb. 15, 2000 as Reissue Patent Re 36,571.

Reissue Application filed Oct. 27, 1999 (O.G. Dec. 28, 1999) Ex. Gp.: 2838; Re. S.N. 09/429,692

Reissue Application filed Mar. 13, 1998 (O.G. Jul. 21, 1998) Ex. Gp.: 2111; Re. S.N. 09/039,106

**INVENTOR:** Rozman, Allen F., Richardson, Texas**ASSIGNEE-AT-ISSUE:** AT&T Corp., Murray Hill, New Jersey (02)**APPL-NO:** 225,027**FILED:** Apr. 8, 1994**REL-US-DATA:**

Continuation-in-part of Ser. No. 54,918, Apr. 29, 1993 now patented 5,303,138 Apr. 12, 1994

**INT-CL:** [6] H02M 7#217**US-CL:** 327#309; 222#87;**CL:** 327;222;**SEARCH-FLD:** 363#20, 21, 89, 97, 126, 127**REF-CITED:****U.S. PATENT DOCUMENTS**

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5,303,138	4/1994	*	Rozman	363#21

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"High Efficiency DC-DC Converter" by I. D. Jitaru; G. Cocina. IEEE, pp. 638-644. May 1994.

**PRIM-EXMR:** Wong, Peter S.**ASST-EXMR:** Riley, Shawn**LEGAL-REP:** Pacher; Eugen E.

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*PR Newswire, July 5, 1988*

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July 5, 1988, Tuesday

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**LENGTH:** 650 words

**HEADLINE:** 'COMING TO AMERICA' RECORD-BREAKING SIX-DAY GROSS IS \$28.4M

**DATeline:** HOLLYWOOD, July 5

**BODY:**

On Wednesday, June 29, the film grossed \$3,780,155; on Thursday, June 30, \$3,224,922; on Friday, July 1, **\$5,528,482**; on Saturday, July 2, \$6,488,578; on Sunday, July 3, \$5,904,041; and on Monday, July 4, the gross was \$3,483,319.

In New York City, playing on 128 screens, "Coming To ...

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1/1 PLUSPAT - (C) QUESTEL-ORBIT  
 PN - US5303138 A 19940412 [US5303138]  
 TI - (A) Low loss synchronous rectifier for application to clamped-mode power converters  
 PA - (A) AT & T BELL LAB (US)  
 IN - (A) ROZMAN ALLEN F (US)  
 AP - US5491893 19930429 [1993US-0054918]  
 PR - US5491893 19930429 [1993US-0054918]  
 IC - (A) H02M-003/335 H02M-007/217  
 EC - H02M-003/335S  
     - H02M-003/335S2S  
     - H02M-007/217  
 PCL - ORIGINAL (O) : 363021060; CROSS-REFERENCE (X) : 363020000 363089000 363097000 363127000  
 DT - Basic  
 CT - US4716514; US4788634; US4857822; US4870555; US4903189; US5066900; US5099406; US5126931; EP0508664  
     - "Improving Power Supply Efficiency with MOSFET Synchronous Rectifiers", R. Kagan, M. Chi, Proceedings of PowerCon 9, 1982, pp. 1-5.

"MOSFETs Move in on Low Voltage Rectification", M. alexander, R. Blanchard, R. Severns, Applications Handbook, Siliconix Technical Article, 1984, Siliconix Inc., pp. 569-580.

"A MOSFET Resonant Synchronous Rectifier for High-Frequency DC/DC Converters" W. Tabisz, F. Lee, D. Chen, PESC Proceedings, 1990, pp. 769-779.

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"Practical Application of MOSFET Synchronous Rectifiers", J. Blanc, Intelec Proceedings, 1991, pp. 495-501.

"High Power SMPS Require Intrinsic Reliability", PCI Proceedings, B. Carsten Sep. 14, 1981, pp. 118-133.

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STG - (A) United States patent  
 AB - A synchronous rectifier for use with a clamped-mode power converter uses in one embodiment a hybrid rectifier with a MOSFET rectifying device active in one first cyclic interval of the conduction/nonconduction sequence of the power switch and a second rectifying device embodied in one illustrative embodiment as a low voltage bipolar diode rectifying device active during an alternative interval to the first conduction/nonconduction interval. The gate drive to the MOSFET device is continuous at a constant level for substantially all of the second interval which enhances efficiency of the rectifier. The bipolar rectifier device may also be embodied as a MOSFET device. The subject rectifier may be used in both forward and flyback power converters.

1/1 LGST - (C) LEGSTAT  
 PN - US 5303138 [US5303138]

AP - US 54918/93 19930429 [1993US-0054918]  
DT - US-P  
ACT - 19930429 US/AE-A  
APPLICATION DATA (PATENT)  
{US 54918/93 19930429 [1993US-0054918]}  
- 19930429 US/AS02  
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Apr. 12, 1994

Low loss synchronous rectifier for application to clamped-mode power converters

**INVENTOR:** Rozman, Allen F., Richardson, Texas**ASSIGNEE-AT-ISSUE:** AT&T Bell Laboratories, Murray Hill, New Jersey (02)**APPL-NO:** 54,918**FILED:** Apr. 29, 1993**INT-CL:** [5] H02M 3#335; H02M 7#217**US-CL:** 363#21; 363#20; 363#89; 363#97; 363#127;**CL:** 363;**SEARCH-FLD:** 363#20, 21, 97, 89, 126, 127; #; H02#M7155; H02#M7217; H02#M3335**REF-CITED:****U. S. PATENT DOCUMENTS**

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"MOSFETs Move in on Low Voltage Rectification", M. alexander, R. Blanchard, R. Severns, Applications Handbook, Siliconix Technical Article, 1984, Siliconix Inc., pp. 569-580.

"A MOSFET Resonant Synchronous Rectifier for High-Frequency DC/DC Converters" W. Tabisz, F. Lee, D. Chen, PESC Proceedings, 1990, pp. 769-779.

"A Simple and Efficient Synchronous Rectifier for Forward DC-DC Converters", N. Murakami, H. Namiki, K. Sakakibara, T. Yachi, APEC Proceedings, 1993 pp. 463-468.

"Practical Application of MOSFET Synchronous Rectifiers", J. Blanc, Inteltec Proceedings, 1991, pp. 495-501.

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May 2, 2001

Re: 09/429,692 (US RE36,571, US 5,528,482, US 5,303,138)

Dear Examiner Riley,

Attached are the requested litigation search results.

Several patent litigation and news databases were searched using Dialog, Lexis-Nexis and Questel-Orbit search systems.

No Litigation cases were found.

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Paul Schulwitz  
308-6559  
CP4-9C18



US00RE 3717

United States Patent [19]

[11] E

Patent Number: Re. 36,571

Rozman

[45] Reissued Date of Patent: \*Feb. 15, 2000

[54] **LOW LOSS SYNCHRONOUS RECTIFIER  
FOR APPLICATION TO CLAMPED-MODE  
POWER CONVERTERS**

[75] Inventor: Allen Frank Rozman, Richardson, Tex.

[73] Assignee: Lucent Technologies Inc., Murray Hill, N.J.

[\*] Notice: This patent is subject to a terminal disclaimer.

[21] Appl. No.: 09/039,106

[22] Filed: Mar. 13, 1998

**Related U.S. Patent Documents**

Reissue of:

[64] Patent No.: 5,528,482  
 Issued: Jun. 18, 1996  
 Appl. No.: 08/225,027  
 Filed: Apr. 8, 1994

U.S. Applications:

[63] Continuation of application No. 08/054,918, Apr. 29, 1993, Pat. No. 5,303,138.

[51] Int. Cl.<sup>7</sup> ..... H02M 7/217

[52] U.S. Cl. .... 363/21; 363/20; 363/89; 327/309

[58] Field of Search ..... 363/20, 21, 89, 363/97, 126, 127; 327/309

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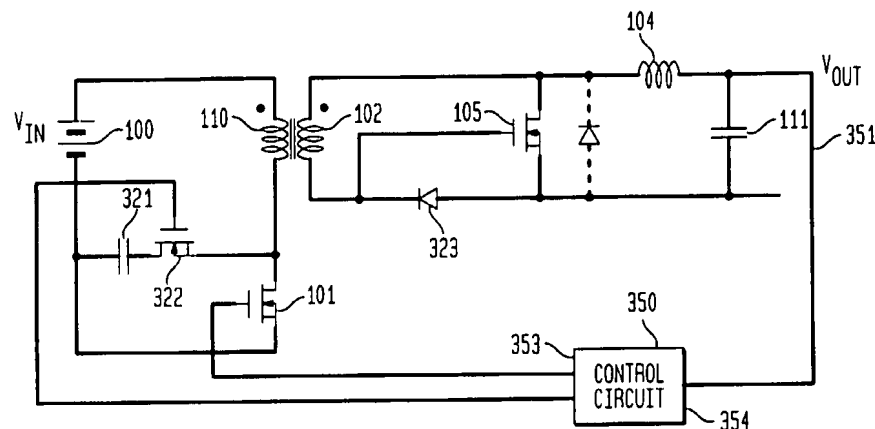
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Primary Examiner—Shawn Riley

[57] **ABSTRACT**

A synchronous rectifier for use with a clamped-mode power converter uses in one embodiment a hybrid rectifier with a MOSFET rectifying device active in one first cyclic interval of the conduction/nonconduction sequence of the power switch and a second rectifying device embodied in one illustrative embodiment as a low voltage bipolar diode rectifying device active during an alternative interval to the first conduction/nonconduction interval. The gate drive to the MOSFET device is continuous at a constant level for substantially all of the second interval which enhances efficiency of the rectifier. The bipolar rectifier device may also be embodied as a MOSFET device. The subject rectifier may be used in both forward and flyback power converters.

**60 Claims, 4 Drawing Sheets**

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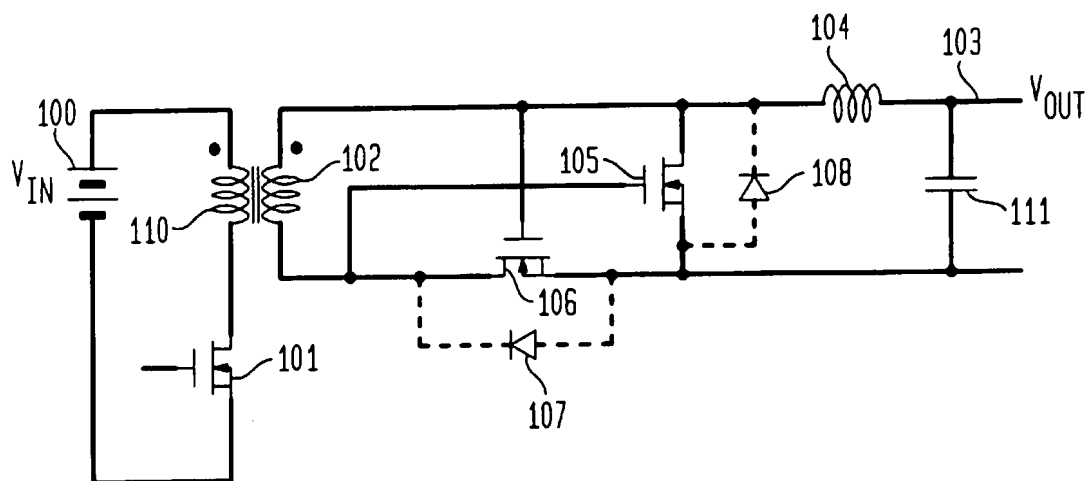
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**FIG. 1**  
(PRIOR ART)



**FIG. 2**  
(PRIOR ART)

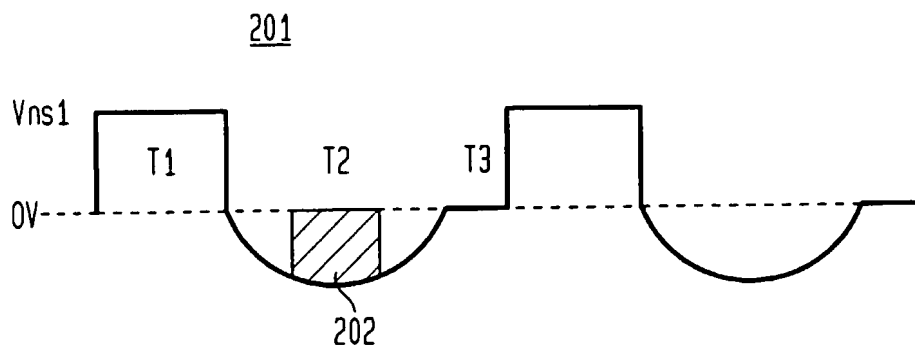


FIG. 3

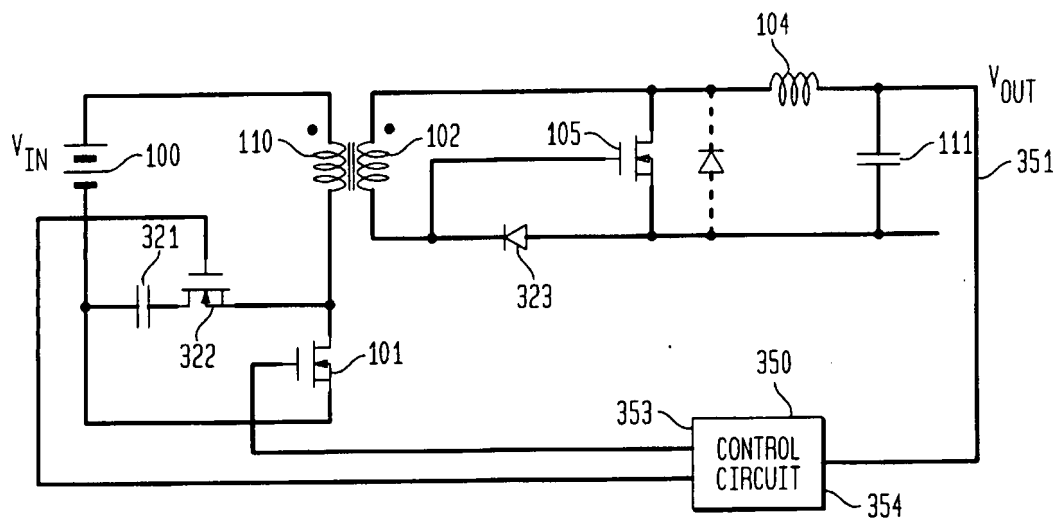


FIG. 4

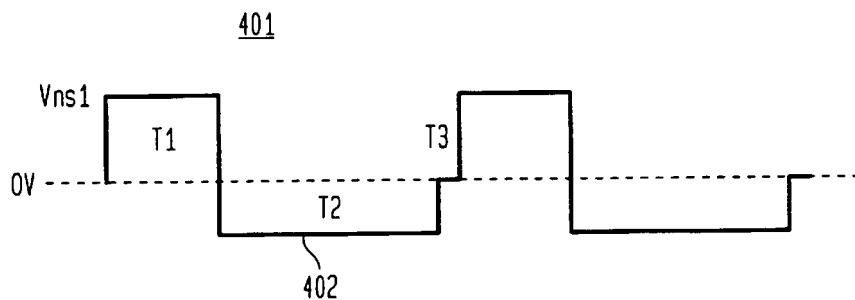


FIG. 5

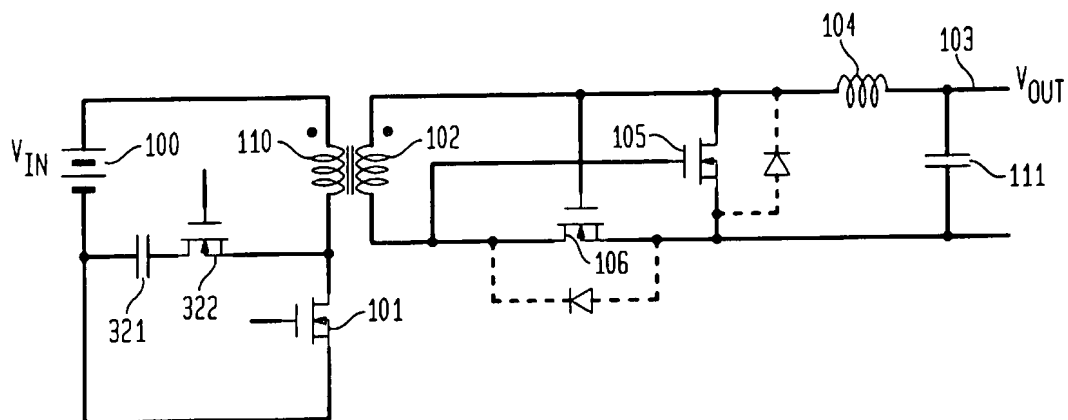


FIG. 6

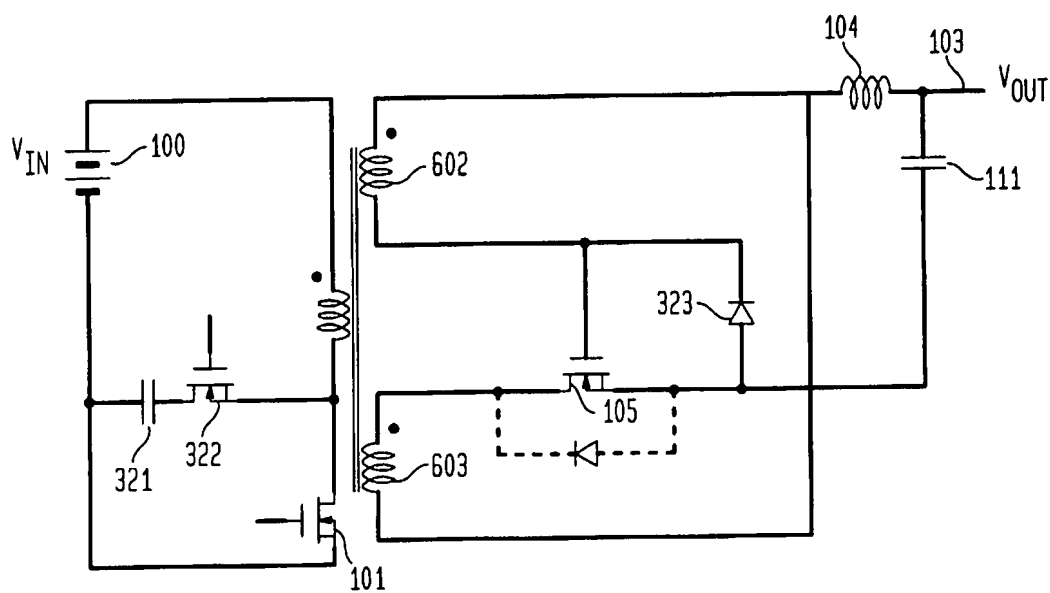


FIG. 7

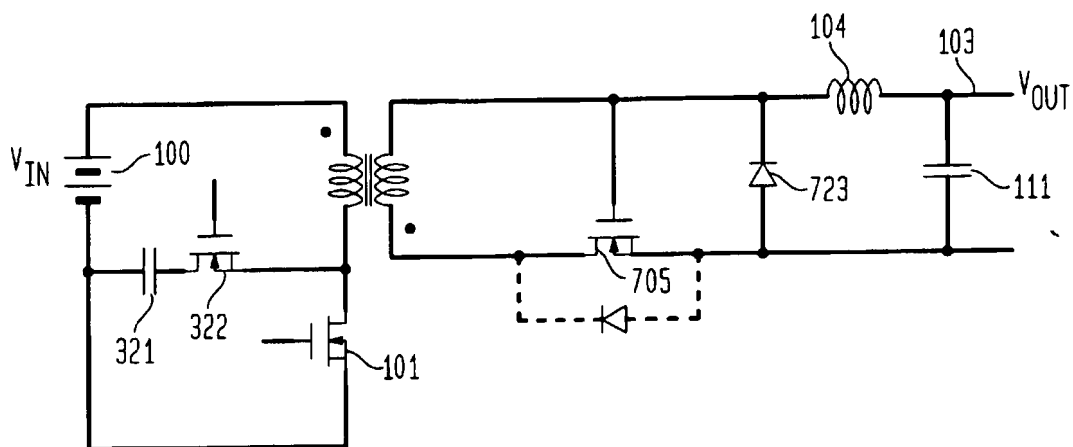
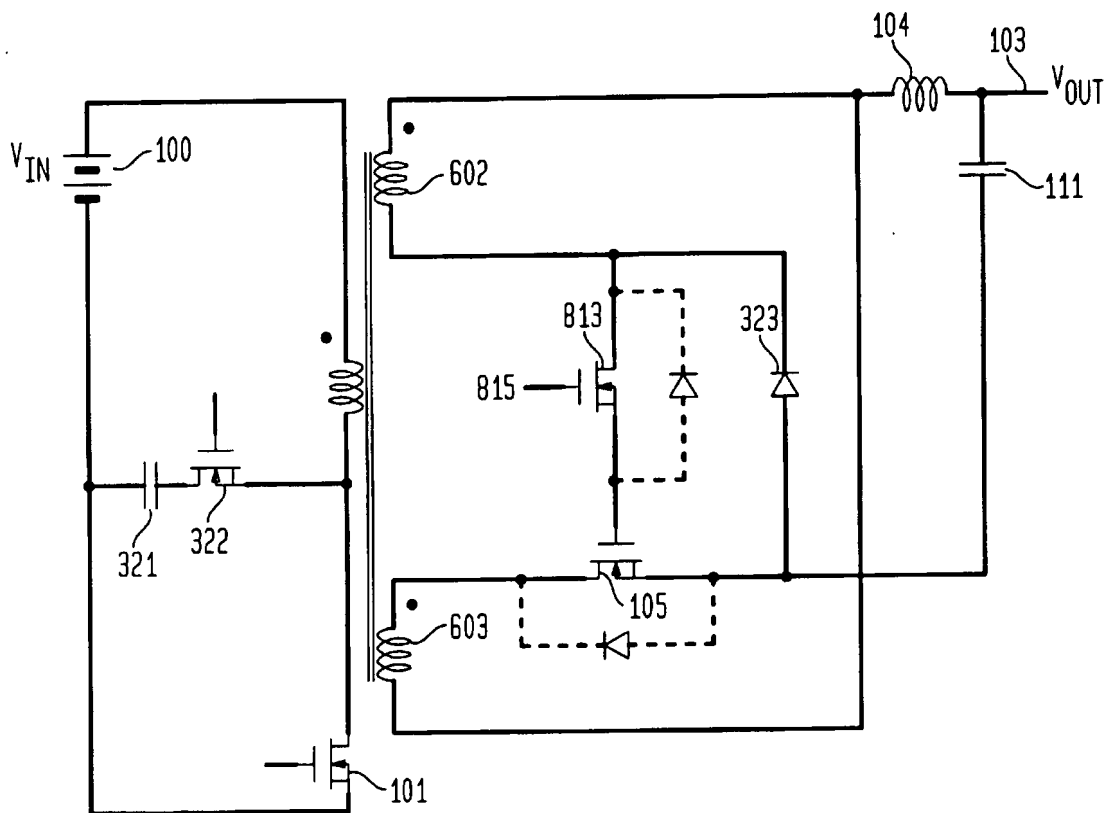


FIG. 8



# LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

This application is a [continuation in part] *reissue of Ser. No. 08/225,027 filed Apr. 8, 1994 U.S. Pat. No. 5,528,482 and a continuation of application Ser. No. 08/054,918 filed on Apr. 29, 1993 now issued as U.S. Pat. No. 5,303,138 on Apr. 12, 1994.*

## FIELD OF THE INVENTION

This invention relates to switching type power converters and in particular to forward and flyback converters having a clamp-mode topology.

## BACKGROUND OF THE INVENTION

Self synchronized rectifiers refer to rectifiers using MOSFET rectifying devices having control terminals which are driven by voltages of the windings of the power transformer in order to provide the rectification of the output of the transformer. Use of synchronous rectifiers has been limited however by the inefficiency of these rectifiers in buck derived converter topologies. Efficiency is limited due to the nature of switching of buck derived converters (i.e. buck, buck-boost, boost converters including forward and flyback topologies) and due to the variability of the transformer reset voltages in the forward type converters. This variability of reset voltage limits the conduction time of one of the MOSFET rectifiers, diminishing the effectiveness and efficiency of the rectifier. This is because the rectifying devices do not conduct for the full switching period and the gate drive energy of one of the rectifiers is dissipated.

## SUMMARY OF THE INVENTION

A synchronous rectifiers is combined with a clamped-mode buck derived power converter. In one illustrative embodiment a hybrid rectifier includes a MOSFET rectifying device active in a first cyclic interval of the conduction/nonconduction sequence of the power switch. A second rectifying device embodied in one illustrative embodiment as a low forward voltage drop bipolar diode rectifying device is active during an alternative interval to the first conduction/nonconduction interval. The gate drive to the MOSFET device is maintained continuous at a constant level for substantially the all of the second interval by the clamping action of the clamping circuitry of the converter. This continuous drive enhances the efficiency of the rectifier.

The bipolar rectifier device may also embodied as a MOSFET device in a rectifier using two MOSFET devices. The subject rectifier may be used in both forward and flyback power converters.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic of a forward converter, of the prior art, having a synchronous rectifier;

FIG. 2 is a voltage waveform of the secondary transformer winding of the converter of FIG. 1;

FIG. 3 is a schematic of a clamped-mode forward converter with a synchronous rectifier embodying the principles of the invention;

FIG. 4 is a voltage waveform of the secondary transformer winding of the converter of FIG. 3;

FIG. 5 is a schematic of another version of a clamped-mode forward converter with a synchronous rectifier embodying the principles of the invention;

FIG. 6 is a schematic of another version of a clamped-mode forward converter with a synchronous rectifier and a center tapped secondary winding embodying the principles of the invention;

FIG. 7 is a schematic of a clamped-mode flyback converter with a synchronous rectifier embodying the principles of the invention; and

FIG. 8 is a schematic of another version of a clamped-mode forward converter with a synchronous rectifier and a center tapped secondary winding embodying the principles of the invention.

## DETAILED DESCRIPTION

In the converter shown in the FIG. 1, a conventional forward topology of the prior art with an isolating power transformer is combined with a self synchronized synchronous rectifier. In such a rectifier controlled devices are used with the control terminals being driven by an output winding of the power transformer.

A DC voltage input  $V_{in}$  at input 100, is connected to the primary winding 110 of the power transformer by a MOSFET power switch 101. The secondary winding 102 is connected to an output lead 103 through an output filter inductor 104 and a synchronous rectifier including the MOSFET rectifying devices 105 and 106. Each rectifying device includes a body diode 108 and 107, respectively.

With the power switch 101 conducting, the input voltage is applied across the primary winding 110. The secondary winding 102 is oriented in polarity to respond to the primary voltage with a current flow through the inductor 104, the load connected to output lead 103 and back through the MOSFET rectifier 106 to the secondary winding 102. Continuity of current flow in the inductor 104, when the power switch 101 is non-conducting, is maintained by the current path provided by the conduction of the MOSFET rectifier 105. An output filter capacitor 111 shunts the output of the converter.

Conductivity of the MOSFET rectifiers is controlled by the gate drive signals provided by the voltage appearing across the secondary winding 102. This voltage is shown graphically by the voltage waveform 201 in FIG. 2. During the conduction interval  $T_1$  of the power switch 101, the secondary winding voltage  $V_{ns1}$  charges the gate of MOSFET 106 to bias it conducting for the entire interval  $T_1$ . The MOSFET 105 is biased non conducting during the  $T_1$  interval. The conducting MOSFET rectifying device 106 provides the current path allowing energy transfer to the output during the interval  $T_1$ . The gate of MOSFET rectifier 106 is charged in response to the input voltage  $V_{in}$ . All of the gate drive energy due to this voltage is dissipated.

As the power MOSFET switch 101 turns off, the voltage  $V_{ns1}$  across the secondary winding 102 reverses polarity just as the time interval  $T_2$  begins. This voltage reversal initiates a reset of the transformer magnetizing inductance, resonantly discharges the gate of MOSFET rectifier 106 and begins charging the gate of MOSFET rectifier 105. As shown by the voltage waveform of FIG. 2, the voltage across the secondary winding 102 is not a constant value, but is rather a variable voltage that collapses to zero in the subsequent time interval  $T_3$ , which occurs prior to the subsequent conduction interval of the power switch 101. This voltage is operative to actually drive the rectifier 105 conducting over only a portion of the time interval  $T_2$  which is

indicated by the cross hatched area 202 associated with the waveform 201 in FIG. 2. This substantially diminishes the performance of the rectifier 105 as a low loss rectifier device. This is aggravated by the fact that the body diode 108 of the rectifier 105 has a large forward voltage drop which is too large to efficiently carry the load current.

The loss of efficiency of the synchronous rectifier limits the overall efficiency of the power converter and has an adverse effect on the possible power density attainable. Since the synchronous rectifier 105 does not continuously conduct throughout the entire switching period, a conventional rectifier diode (e.g. connected in shunt with rectifier 105) capable of carrying the load current is required in addition to MOSFET rectifier 105. This inefficiency is further aggravated by the gate drive energy dissipation associated with the MOSFET rectifier 106. This gate drive loss may exceed the conduction loss for MOSFET rectifier 106, at high switching frequency (e.g. >300 kHz).

The efficiency of a forward converter with synchronous rectification is significantly improved according to the invention by using a clamp circuit arrangement to limit the reset voltage and by using a low forward voltage drop diode in the rectifying circuitry. Such an arrangement is shown in the schematic of FIG. 3. In this forward power converter the power MOSFET device 101 is shunted by a series connection of a clamp capacitor 321 and a MOSFET switch device 322. The conducting intervals of power switch 101 and MOSFET device 322 are mutually exclusive. The duty cycle of power switch 101 is D and the duty cycle of MOSFET device 322 is 1-D. The voltage inertia of the capacitor 321 limits the amplitude of the reset voltage appearing across the magnetizing inductance during the non conducting interval of the MOSFET power switch 101.

The diode 323 of the synchronous rectifier, shown in FIG. 3, has been substituted for the MOSFET device 106 shown in the FIG. 1. Due to the dissipation of gate drive energy the overall contribution of the MOSFET rectifier 106 in FIG. 1 is limited. The clamping action of the clamping circuitry results in the constant voltage level 402 shown in the voltage waveform 401, across the secondary winding 102, in the time period  $T_2$ . This constant voltage applied to the gate drive of the MOSFET rectifier 105 drives it into conduction for the entire  $T_2$  reset interval. In this arrangement there is no need for a bipolar or a body diode shunting the MOSFET rectifier 105. An advantage in the clamped mode converter is that the peak inverse voltage applied to the diode 323 is much less than that applied to the similarly positioned MOSFET device in FIG. 1. Accordingly the diode 323 may be a very efficient low voltage diode which may be embodied by a low voltage diode normally considered unsuitable for rectification purposes.

In the operation of the clamped mode forward converter the MOSFET switch 322 is turned off just prior to turning the MOSFET power switch on. Energy stored in the parasitic capacitances of the MOSFET switching devices 101 and 322 is commutated to the leakage inductance of the power transformer, discharging the capacitance down toward zero voltage. During the time interval  $T_3$  shown in FIG. 4, voltage across the primary winding is supported by the leakage inductance. The voltage across the secondary winding 102 drops to zero value as shown in the FIG. 4. With this zero voltage level of the secondary winding, the output inductor resonantly discharges the gate capacitance of the MOSFET rectifying device 105 and eventually forward biases the the bipolar diode 323. The delay time  $T_3$  is a fixed design parameter and is a factor in the control of the power switches 101 and 322, which may be switched to accommodate soft

waveforms. This synchronous rectification circuit of FIG. 3 provides the desired efficiencies lacking in the arrangement of the circuit shown in FIG. 1.

Control of the conductivity of the power switching devices 101 and 322 is by means of a control circuit 350, which is connected, by lead 351, to an output terminal 103 of the converter to sense the output terminal voltage. The control circuit 350 is connected, by leads 353 and 354, to the drive terminals of the power switches 101 and 322. The drive signals are controlled to regulate an the output voltage at output terminal. The exact design of a control circuit, to achieve the desired regulation, is well known in the art and hence is not disclosed in detail herein. This control circuit 350 is suitable for application to the converters of FIGS. 5, 6, 7 and 8.

A modified version of the circuit of FIG. 3 is shown in the circuit schematic of the FIG. 5. The converter of FIG. 5 is a clamped mode forward converter having two gated synchronous rectifying devices 105 and 106. In this embodiment of the synchronous rectifier the synchronized rectifying device 106 can be used without adversely affecting the converter efficiency at lower operating frequencies.

The circuit of FIG. 6 is a clamped mode forward converter having a rectifier analogous to that of FIG. 3 in using one bipolar rectifying diode. The secondary winding is tapped creating two secondary winding segments 603 and 602.

The converter of FIG. 7 operates in a flyback mode. The bipolar and synchronous rectifier device are in a reversed connection from the connection of FIG. 3 to accommodate the flyback operation.

In some applications direct application of the gate drive signal directly from the secondary winding may result in voltage spikes exceeding the rating of the gate. A small signal MOSFET device 813 is connected to couple the gate drive to the MOSFET rectifying device 105. This device may be controlled by the control drive lead 815 to limit the peak voltage applied to the gate of rectifier 105. The MOSFET synchronous rectifier is then discharged through the body diode of the MOSFET device 813.

I claim:

1. In a power converter, comprising:

an input for accepting a DC voltage;

a power transformer including a primary and secondary winding;

a power switch for periodically connecting the input to the primary winding;

an output for accepting a load to be energized;

clamping means for limiting a voltage and extending the voltage's duration across the secondary winding at a substantially constant amplitude during substantially an entire extent of a clamping interval of a cyclic period of the power converter;

a rectifier connecting the secondary winding to the output; and including:

a synchronous rectification device with a control terminal connected to be responsive to signal across the secondary winding such that the synchronous rectification device conducts a load current during substantially the entire extent of the clamping interval; and

a rectifying device connected for enabling conduction of the load current during a second interval other than the clamping interval.

2. In a power converter, comprising

an input for accepting a DC voltage;

5

- a power transformer including a primary and secondary winding;
- a power switch for periodically connecting the input to the primary winding during a second interval of a cyclic period;
- an output for accepting a load to be energized;
- clamping means for limiting a voltage and extending the voltage's duration across the secondary winding at a substantially constant amplitude during substantially an entire extent of a clamping interval of a cyclic period of the power converter;
- a rectifier circuit connecting the secondary winding to the output; and including:
  - a first synchronous rectification device with a control terminal connected to be responsive to a signal across the secondary winding such that the synchronous rectification device conducts a load current during substantially the entire extent of the clamping interval; and
  - a second synchronous rectification device with a control terminal connected to be responsive to a signal across the secondary winding such that the second synchronous rectification device conducts the load current during substantially an entire extent of the second interval other than the clamping interval.
- 3. In a power converter as claimed in claim 1 or 2, comprising:
  - the converter connected to operate as a forward type converter.
- 4. In a power converter as claimed in claim 1 or 2, comprising:
  - the converter connected to operate as a flyback type converter.
- 5. A switching mode power converter, comprising:
  - a power transformer including a magnetizing inductance requiring periodic recycling;
  - a first power stage for converting a DC input into a periodic pulsed voltage applied to primary winding of the transformer, including:
    - a clamping circuit for limiting a voltage of the transformer during the periodic recycling at a substantially constant amplitude and extending the voltage duration to maintain a constant voltage for substantially an entire extent of periodic recycling;
  - a second power stage for rectifying an output of a secondary winding of the transformer and applying it to a load to be energized, including:
    - a synchronous rectifier including a first rectifying device with a control gate connected to be responsive to a signal across the secondary winding such that the synchronous rectification device conducts a load current during the periodic recycling when the clamping circuit is active; and
    - a second rectifying device connected for enabling conduction of the load current when the first rectifying device is nonconducting.
- 6. A switching mode power converter as claimed in claim 5, further comprising:
  - the second rectifying device comprises a diode.
- 7. A switching mode power converter as claimed in claim 5, further comprising:
  - the second rectifying device comprises a rectifying device with a control gate connected to be responsive to a signal of the secondary winding.
- 8. A switching mode power converter as claimed in claim 6 or 7, further comprising:

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- the secondary winding tapped and separated into first and second winding segments, and the first rectifying device is connected to the first winding segment and the second rectifying device is connected to the second winding segment.
- 9. A switching mode power converter as claimed in claim 6 or 7, further comprising:
  - the converter connected to operate as a forward type converter.
- 10. A switching mode power converter as claimed in claim 6 or 7, further comprising:
  - the converter connected to operate as a flyback type converter.
- 11. A power converter, comprising:
  - a power transformer having a plurality of windings;
  - a clamping circuit, coupled to said power transformer, that limits a voltage across at least one of said plurality of windings during a clamping interval of said power converter; and
  - a synchronous rectification device coupled to said power transformer and having a control terminal responsive to a signal across at least one of said plurality of windings such that said synchronous rectification device is active for substantially all of said clamping interval.
- 12. The power converter as claimed in claim 11 wherein said clamping circuit is directly connected to said power transformer.
- 13. The power converter as claimed in claim 11 wherein said clamping circuit is coupled to a primary winding of said power transformer.
- 14. The power converter as claimed in claim 11 wherein said power transformer has a center-tapped secondary winding.
- 15. The power converter as claimed in claim 11 further comprising a power switch that connects a primary winding of said power transformer to an input of said power converter during a first cyclic interval of said power converter.
- 16. The power converter as claimed in claim 11 further comprising a further synchronous rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.
- 17. The power converter as claimed in claim 11 further comprising a rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.
- 18. The power converter as claimed in claim 11 wherein said clamping circuit comprises a switching device connected in series with a capacitor.
- 19. The power converter as claimed in claim 18 further comprising a control circuit that controls said switching device.
- 20. The power converter as claimed in claim 11 wherein said power converter operates in one of:
  - a forward mode,
  - a flyback mode, and
  - a forward/flyback mode.
- 21. A power converter, comprising:
  - a power transformer having a plurality of windings;
  - a synchronous rectification device coupled to at least one of said plurality of windings and having a control terminal; and
  - a clamping circuit, coupled to said power transformer, that limits a voltage applied to said control terminal such that said synchronous rectification device is active for substantially all of a clamping interval.

22. The power converter as claimed in claim 21 wherein said clamping circuit is directly connected to said power transformer.

23. The power converter as claimed in claim 21 wherein said clamping circuit is coupled to a primary winding of said power transformer.

24. The power converter as claimed in claim 21 wherein said power transformer has a center-tapped secondary winding.

25. The power converter as claimed in claim 21 further comprising a power switch that connects a primary winding of said power transformer to an input of said power converter during a first cyclic interval of said power converter.

26. The power converter as claimed in claim 21 further comprising a further synchronous rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.

27. The power converter as claimed in claim 21 further comprising a rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.

28. The power converter as claimed in claim 21 wherein said clamping circuit comprises a switching device connected in series with a capacitor.

29. The power converter as claimed in claim 28 further comprising a control circuit that controls said switching device.

30. The power converter as claimed in claim 21 wherein said power converter operates in one of:

- a forward mode,
- a flyback mode, and
- a forward/flyback mode.

31. A power converter, comprising:

- a power transformer having a plurality of windings;
- a synchronous rectification device having a control terminal and coupled to at least one of said plurality of windings; and
- a clamping circuit, coupled to said power transformer, that limits a voltage applied to said control terminal such that said synchronous rectification device conducts a load current for substantially all of a clamping interval.

32. The power converter as claimed in claim 31 wherein said clamping circuit is directly connected to said power transformer.

33. The power converter as claimed in claim 31 wherein said clamping circuit is coupled to a primary winding of said power transformer.

34. The power converter as claimed in claim 31 wherein said power transformer has a center-tapped secondary winding.

35. The power converter as claimed in claim 31 further comprising a power switch that connects a primary winding of said power transformer to an input of said power converter during a first cyclic interval of said power converter.

36. The power converter as claimed in claim 31 further comprising a further synchronous rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.

37. The power converter as claimed in claim 31 further comprising a rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.

38. The power converter as claimed in claim 31 wherein said clamping circuit comprises a switching device connected in series with a capacitor.

39. The power converter as claimed in claim 37 further comprising a control circuit that controls said switching device.

40. The power converter as claimed in claim 31 wherein said power converter operates in one of:

- a forward mode,
- a flyback mode, and
- a forward/flyback mode.

41. A power converter, comprising:

- a power transformer having a plurality of windings;
- a synchronous rectification device having a control terminal responsive to a drive signal and coupled to at least one of said plurality of windings; and
- a clamping circuit, coupled to said power transformer, that limits said drive signal applied to said control terminal such that said drive signal is continuous for substantially all of a clamping interval.

42. The power converter as claimed in claim 41 wherein said clamping circuit is directly connected to said power transformer.

43. The power converter as claimed in claim 41 wherein said clamping circuit is coupled to a primary winding of said power transformer.

44. The power converter as claimed in claim 41 wherein said power transformer has a center-tapped secondary winding.

45. The power converter as claimed in claim 41 further comprising a power switch that connects a primary winding of said power transformer to an input of said power converter during a first cyclic interval of said power converter.

46. The power converter as claimed in claim 41 further comprising a further synchronous rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.

47. The power converter as claimed in claim 41 further comprising a rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.

48. The power converter as claimed in claim 41 wherein said clamping circuit comprises a switching device connected in series with a capacitor.

49. The power converter as claimed in claim 48 further comprising a control circuit that controls said switching device.

50. The power converter as claimed in claim 41 wherein said power converter operates in one of:

- a forward mode,
- a flyback mode, and
- a forward/flyback mode.

51. A power converter, comprising:

- an input that accepts a DC voltage;
- an output that provides current to a load;
- a power transformer having at least one primary winding and at least one secondary winding;
- a power switch that periodically connects said input to said at least one primary winding during a first cyclic interval of said power converter;
- a clamping circuit that limits a voltage across said at least one secondary winding during a clamping interval of said power converter; and
- a synchronous rectification device having a control terminal responsive to a signal across said at least one secondary winding such that said synchronous rectification device is active for substantially all of said clamping interval.

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52. The power converter as claimed in claim 51 wherein said clamping circuit is directly connected to said power transformer.

53. The power converter as claimed in claim 51 wherein said clamping circuit is coupled to said at least one primary winding of said power transformer.

54. The power converter as claimed in claim 51 wherein said at least one secondary winding has a center-tap.

55. The power converter as claimed in claim 51 further comprising a voltage limiting device coupled to said synchronous rectification device.

56. The power converter as claimed in claim 51 further comprising a further synchronous rectification device, coupled to said power transformer, that is active during a first cyclic interval of said power converter.

57. The power converter as claimed in claim 51 further comprising a rectification device, coupled to said power

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transformer, that is active during a first cyclic interval of said power converter.

58. The power converter as claimed in claim 51 wherein said clamping circuit comprises a switching device connected in series with a capacitor.

59. The power converter as claimed in claim 58 further comprising a control circuit that controls said switching device.

60. The power converter as claimed in claim 51 wherein said power converter operates in one of:

- a forward mode,
- a flyback mode, and
- a forward/flyback mode.

\* \* \* \* \*



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## United States Patent [19]

Rozman

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[45] Date of Patent: \*Jun. 18, 1996

[54] LOW LOSS SYNCHRONOUS RECTIFIER  
FOR APPLICATION TO CLAMPED-MODE  
POWER CONVERTERS

5,303,138 4/1994 Rozman 363/21

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[\*] Notice: The term of this patent shall not extend  
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5,303,138.

[21] Appl. No.: 225,027

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## Related U.S. Application Data

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No. 5,303,138.

[51] Int. Cl.<sup>6</sup> H02M 7/217

[52] U.S. Cl. 363/21; 363/20; 363/89;  
327/309

[58] Field of Search 363/20, 21, 89,  
363/97, 126, 127

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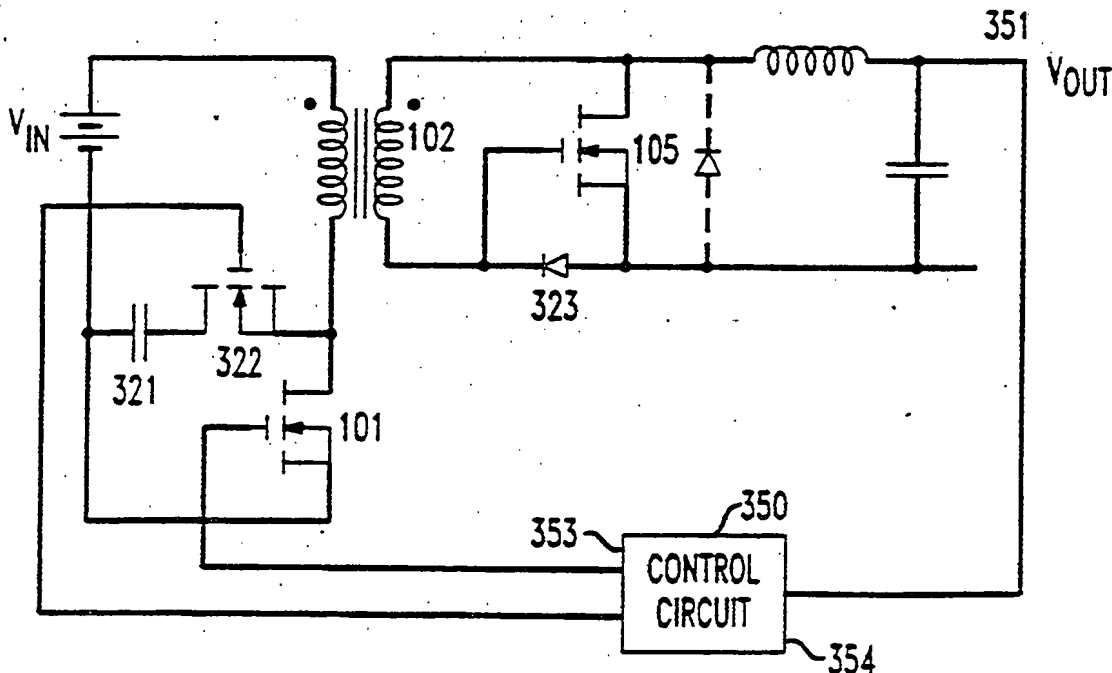
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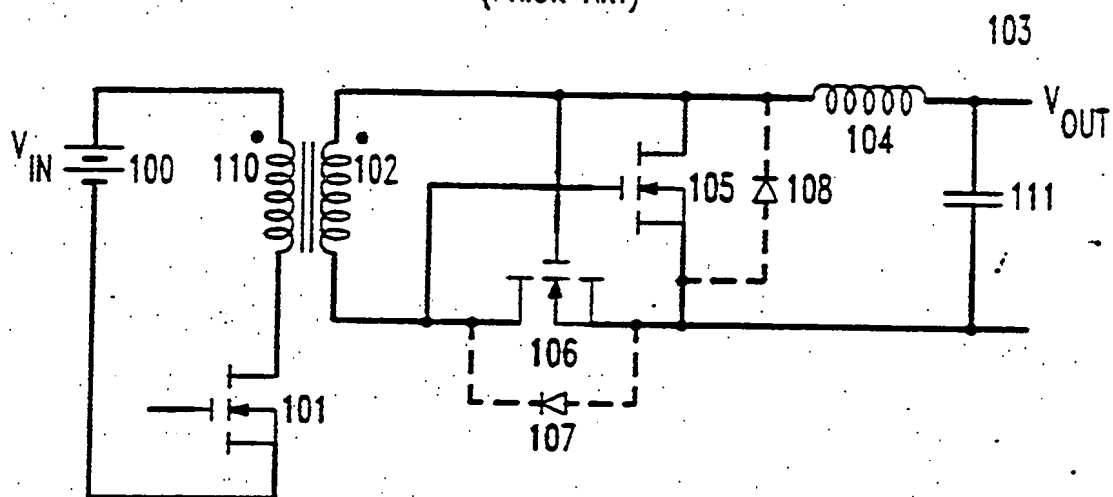
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**FIG. 1**  
(PRIOR ART)



**FIG. 2**  
(PRIOR ART)

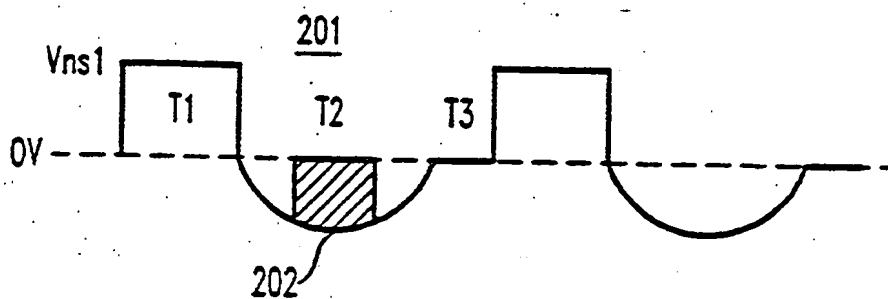


FIG. 3

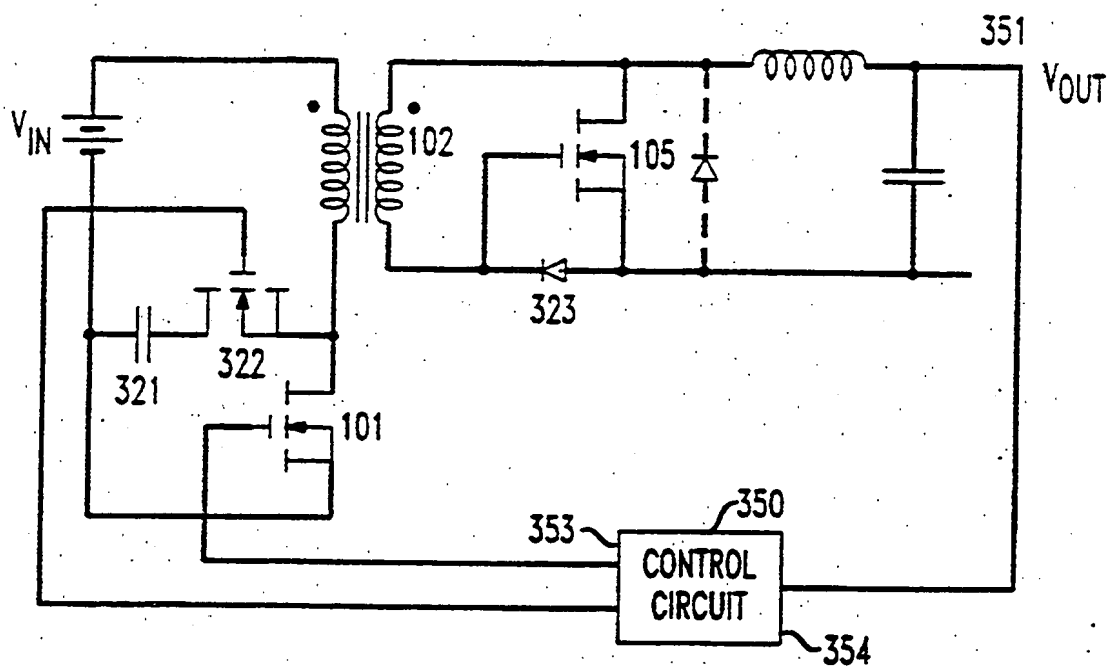


FIG. 4

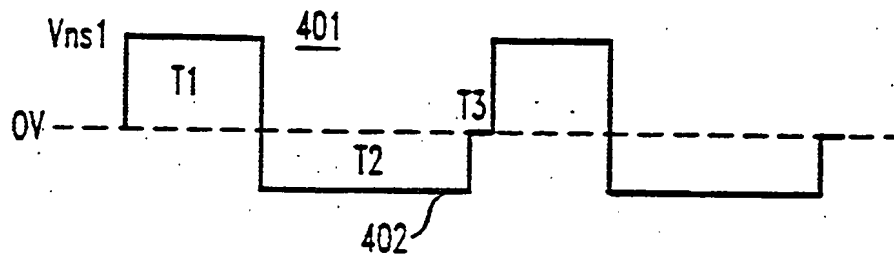


FIG. 5

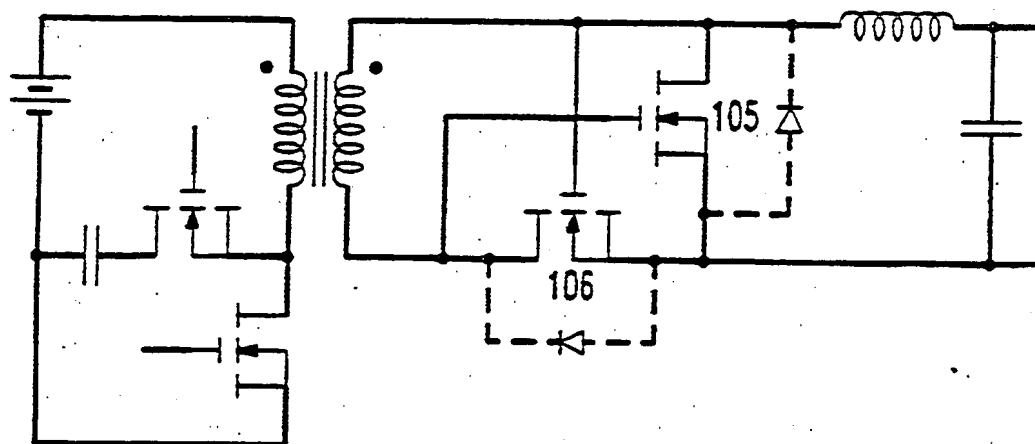


FIG. 6

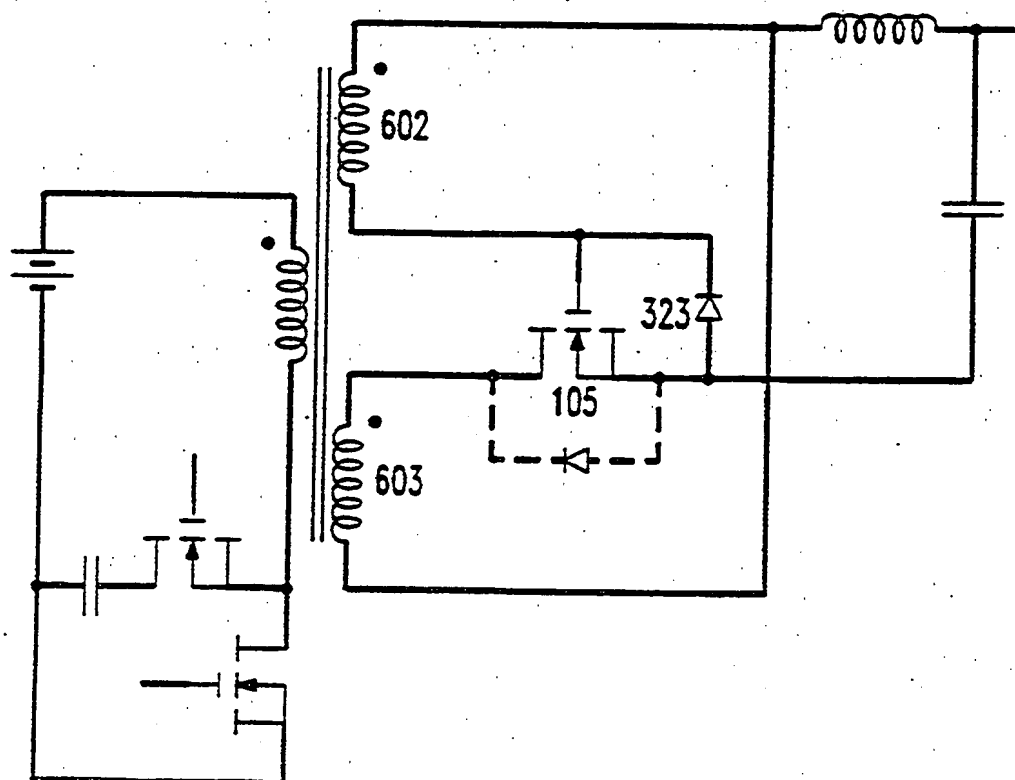


FIG. 7

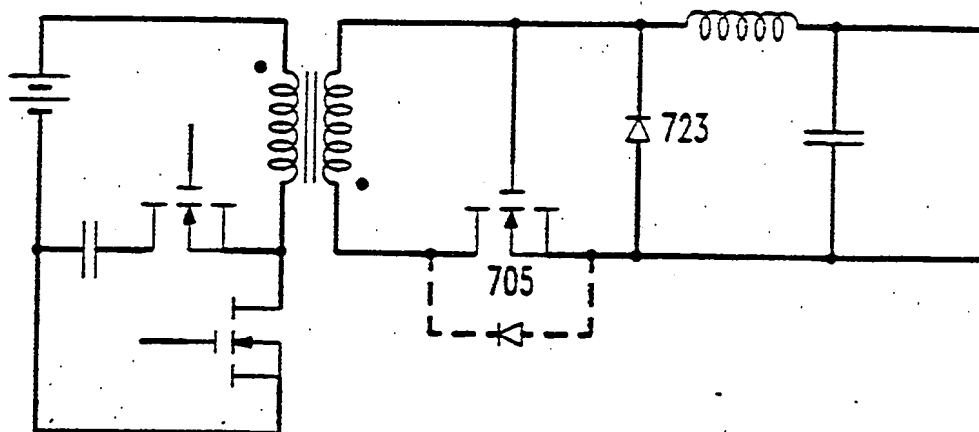
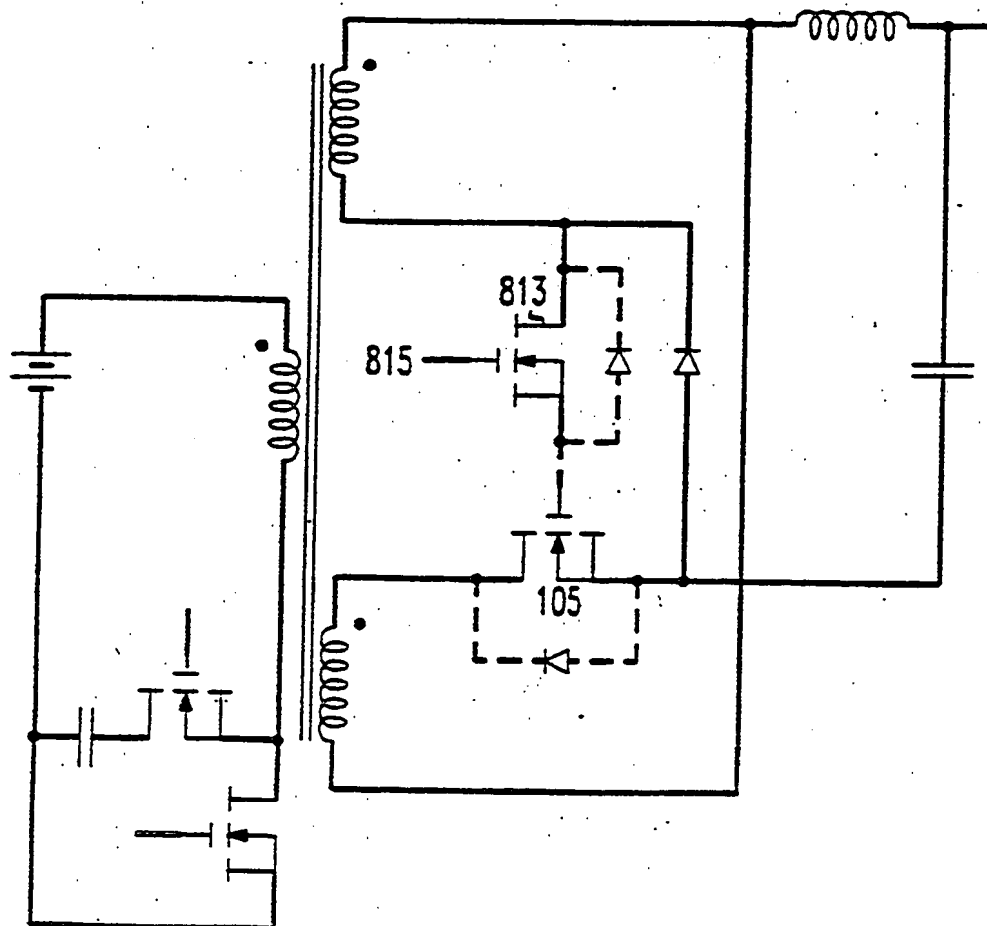


FIG. 8



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# LOW LOSS SYNCHRONOUS RECTIFIER FOR APPLICATION TO CLAMPED-MODE POWER CONVERTERS

This application is a continuation in part of application Ser. No. 08/054,918 filed on Apr. 29, 1993 now issued as U.S. Pat. No. 5,303,138 on Apr. 12, 1994.

## FIELD OF THE INVENTION

This invention relates to switching type power converters and in particular to forward and flyback converters having a clamp-mode topology.

## BACKGROUND OF THE INVENTION

Self synchronized rectifiers refer to rectifiers using MOSFET rectifying devices having control terminals which are driven by voltages of the windings of the power transformer in order to provide the rectification of the output of the transformer. Use of synchronous rectifiers has been limited however by the inefficiency of these rectifiers in buck derived converter topologies. Efficiency is limited due to the nature of switching of buck derived converters (i.e. buck, buck-boost, boost converters including forward and flyback topologies) and due to the variability of the transformer reset voltages in the forward type converters. This variability of reset voltage limits the conduction time of one of the MOSFET rectifiers, diminishing the effectiveness and efficiency of the rectifier. This is because the rectifying devices do not conduct for the full switching period and the gate drive energy of one of the rectifiers is dissipated.

## SUMMARY OF THE INVENTION

A synchronous rectifier is combined with a clamped-mode buck derived power converter. In one illustrative embodiment a hybrid rectifier includes a MOSFET rectifying device active in a first cyclic interval of the conduction/nonconduction sequence of the power switch. A second rectifying device embodied in one illustrative embodiment as a low forward voltage drop bipolar diode rectifying device is active during an alternative interval to the first conduction/nonconduction interval. The gate drive to the MOSFET device is maintained continuous at a constant level for substantially the all of the second interval by the clamping action of the clamping circuitry of the converter. This continuous drive enhances the efficiency of the rectifier.

The bipolar rectifier device may also embodied as a MOSFET device in a rectifier using two MOSFET devices. The subject rectifier may be used in both forward and flyback power converters.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic of a forward converter, of the prior art, having a synchronous rectifier;

FIG. 2 is a voltage waveform of the secondary transformer winding of the converter of FIG. 1;

FIG. 3 is a schematic of a clamped-mode forward converter with a synchronous rectifier embodying the principles of the invention;

FIG. 4 is a voltage waveform of the secondary transformer winding of the converter of FIG. 3;

FIG. 5 is a schematic of another version of a clamped-mode forward converter with a synchronous rectifier embodying the principles of the invention;

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FIG. 6 is a schematic of another version of a clamped-mode forward converter with a synchronous rectifier and a center tapped secondary winding embodying the principles of the invention;

FIG. 7 is a schematic of a clamped-mode flyback converter with a synchronous rectifier embodying the principles of the invention; and

FIG. 8 is a schematic of another version of a clamped-mode forward converter with a synchronous rectifier and a center tapped secondary winding embodying the principles of the invention.

## DETAILED DESCRIPTION

In the converter shown in the FIG. 1, a conventional forward topology of the prior art with an isolating power transformer is combined with a self synchronized synchronous rectifier. In such a rectifier controlled devices are used with the control terminals being driven by an output winding of the power transformer.

A DC voltage input  $V_{in}$  at input 100, is connected to the primary winding 110 of the power transformer by a MOSFET power switch 101. The secondary winding 102 is connected to an output lead 103 through an output filter inductor 104 and a synchronous rectifier including the MOSFET rectifying devices 105 and 106. Each rectifying device includes a body diode 108 and 107, respectively.

With the power switch 101 conducting, the input voltage is applied across the primary winding 110. The secondary winding 102 is oriented in polarity to respond to the primary voltage with a current flow through the inductor 104, the load connected to output lead 103 and back through the MOSFET rectifier 106 to the secondary winding 102. Continuity of current flow in the inductor 104, when the power switch 101 is non-conducting, is maintained by the current path provided by the conduction of the MOSFET rectifier 105. An output filter capacitor 111 shunts the output of the converter.

Conductivity of the MOSFET rectifiers is controlled by the gate drive signals provided by the voltage appearing across the secondary winding 102. This voltage is shown graphically by the voltage waveform 201 in FIG. 2. During the conduction interval  $T_1$  of the power switch 101, the secondary winding voltage  $V_{rs1}$  charges the gate of MOSFET 106 to bias it conducting for the entire interval  $T_1$ . The MOSFET 105 is biased non conducting during the  $T_1$  interval. The conducting MOSFET rectifying device 106 provides the current path allowing energy transfer to the output during the interval  $T_1$ . The gate of MOSFET rectifier 106 is charged in response to the input voltage  $V_{in}$ . All of the gate drive energy due to this voltage is dissipated.

As the power MOSFET switch 101 turns off, the voltage  $V_{rs1}$  across the secondary winding 102 reverses polarity just as the time interval  $T_2$  begins. This voltage reversal initiates a reset of the transformer magnetizing inductance, resonantly discharges the gate of MOSFET rectifier 106 and begins charging the gate of MOSFET rectifier 105. As shown by the voltage waveform of FIG. 2, the voltage across the secondary winding 102 is not a constant value, but is rather a variable voltage that collapses to zero in the subsequent time interval  $T_3$ , which occurs prior to the subsequent conduction interval of the power switch 101. This voltage is operative to actually drive the rectifier 105 conducting over only a portion of the time interval  $T_2$  which is indicated by the cross hatched area 202 associated with the waveform 201 in FIG. 2. This substantially diminishes the

performance of the rectifier 105 as a low loss rectifier device. This is aggravated by the fact that the body diode 108 of the rectifier 105 has a large forward voltage drop which is too large to efficiently carry the load current.

The loss of efficiency of the synchronous rectifier limits the overall efficiency of the power converter and has an adverse effect on the possible power density attainable. Since the synchronous rectifier 105 does not continuously conduct throughout the entire switching period, a conventional rectifier diode (e.g. connected in shunt with rectifier 105) capable of carrying the load current is required in addition to MOSFET rectifier 105. This inefficiency is further aggravated by the gate drive energy dissipation associated with the MOSFET rectifier 106. This gate drive loss may exceed the conduction loss for MOSFET rectifier 106, at high switching frequency (e.g. >300 kHz).

The efficiency of a forward converter with synchronous rectification is significantly improved according to the invention by using a clamp circuit arrangement to limit the reset voltage and by using a low forward voltage drop diode in the rectifying circuitry. Such an arrangement is shown in the schematic of FIG. 3. In this forward power converter the power MOSFET device 101 is shunted by a series connection of a clamp capacitor 321 and a MOSFET switch device 322. The conducting intervals of power switch 101 and MOSFET device 322 are mutually exclusive. The duty cycle of power switch 101 is D and the duty cycle of MOSFET device 322 is 1-D. The voltage inertia of the capacitor 321 limits the amplitude of the reset voltage appearing across the magnetizing inductance during the non conducting interval of the MOSFET power switch 101.

The diode 323 of the synchronous rectifier, shown in FIG. 3, has been substituted for the MOSFET device 106 shown in the FIG. 1. Due to the dissipation of gate drive energy the overall contribution of the MOSFET rectifier 106 in FIG. 1 is limited. The clamping action of the clamping circuitry results in the constant voltage level 402 shown in the voltage waveform 401, across the secondary winding 102, in the time period  $T_2$ . This constant voltage applied to the gate drive of the MOSFET rectifier 105 drives it into conduction for the entire  $T_2$  reset interval. In this arrangement there is no need for a bipolar or a body diode shunting the MOSFET rectifier 105. An advantage in the clamped mode converter is that the peak inverse voltage applied to the diode 323 is much less than that applied to the similarly positioned MOSFET device in FIG. 1. Accordingly the diode 323 may be a very efficient low voltage diode which may be embodied by a low voltage diode normally considered unsuitable for rectification purposes.

In the operation of the clamped mode forward converter the MOSFET switch 322 is turned off just prior to turning the MOSFET power switch on. Energy stored in the parasitic capacitances of the MOSFET switching devices 101 and 322 is commutated to the leakage inductance of the power transformer, discharging the capacitance down toward zero voltage. During the time interval  $T_3$  shown in FIG. 4, voltage across the primary winding is supported by the leakage inductance. The voltage across the secondary winding 102 drops to zero value as shown in the FIG. 4. With this zero voltage level of the secondary winding, the output inductor resonantly discharges the gate capacitance of the MOSFET rectifying device 105 and eventually forward biases the bipolar diode 323. The delay time  $T_3$  is a fixed design parameter and is a factor in the control of the power switches 101 and 322, which may be switched to accommodate soft waveforms. This synchronous rectification circuit of FIG. 3 provides the desired efficiencies lacking in the arrangement of the circuit shown in FIG. 1.

Control of the conductivity of the power switching devices 101 and 322 is by means of a control circuit 350, which is connected, by lead 351, to an output terminal 103 of the converter to sense the output terminal voltage. The control circuit 350 is connected, by leads 353 and 354, to the drive terminals of the power switches 101 and 322. The drive signals are controlled to regulate the output voltage at output terminal. The exact design of a control circuit, to achieve the desired regulation, is well known in the art and hence is not disclosed in detail herein. This control circuit 350 is suitable for application to the converters of FIGS. 5, 6, 7 and 8.

A modified version of the circuit of FIG. 3 is shown in the circuit schematic of the FIG. 5. The converter of FIG. 5 is a clamped mode forward converter having two gated synchronous rectifying devices 105 and 106. In this embodiment of the synchronous rectifier the synchronized rectifying device 106 can be used without adversely affecting the converter efficiency at lower operating frequencies.

The circuit of FIG. 6 is a clamped mode forward converter having a rectifier analogous to that of FIG. 3 in using one bipolar rectifying diode. The secondary winding is tapped creating two secondary winding segments 603 and 602.

The converter of FIG. 7 operates in a flyback mode. The bipolar and synchronous rectifier device are in a reversed connection from the connection of FIG. 3 to accommodate the flyback operation.

In some applications direct application of the gate drive signal directly from the secondary winding may result in voltage spikes exceeding the rating of the gate. A small signal MOSFET device 813 is connected to couple the gate drive to the MOSFET rectifying device 105. This device may be controlled by the control drive lead 815 to limit the peak voltage applied to the gate of rectifier 105. The MOSFET synchronous rectifier is then discharged through the body diode of the MOSFET device 813.

I claim:

1. In a power converter, comprising:
  - an input for accepting a DC voltage;
  - a power transformer including a primary and secondary winding;
  - a power switch for periodically connecting the input to the primary winding;
  - an output for accepting a load to be energized;
  - clamping means for limiting a voltage and extending the voltage's duration across the secondary winding at a substantially constant amplitude during substantially an entire extent of a clamping interval of a cyclic period of the power converter;
  - a rectifier circuit connecting the secondary winding to the output; and including:
    - a synchronous rectification device with a control terminal connected to be responsive to a signal across the secondary winding such that the synchronous rectification device conducts a load current during substantially the entire extent of the clamping interval; and
    - a rectifying device connected for enabling conduction of the load current during a second interval other than the clamping interval.
2. In a power converter, comprising
  - an input for accepting a DC voltage;
  - a power transformer including a primary and secondary winding;
  - a power switch for periodically connecting the input to the primary winding during a second interval of a cyclic period;

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an output for accepting a load to be energized;

clamping means for limiting a voltage and extending the voltage's duration across the secondary winding at a substantially constant amplitude during substantially an entire extent of a clamping interval of a cyclic period of the power converter;

a rectifier circuit connecting the secondary winding to the output; and including:

a first synchronous rectification device with a control terminal connected to be responsive to a signal across the secondary winding such that the synchronous rectification device conducts a load current during substantially the entire extent of the clamping interval, and

a second synchronous rectification device with a control terminal connected to be responsive to a signal across the secondary winding such that the second synchronous rectification device conducts the load current during substantially an entire extent of the second interval other than the clamping interval.

3. In a power converter as claimed in claim 1 or 2, comprising:

the converter connected to operate as a forward type converter.

4. In a power converter as claimed in claim 1 or 2, comprising:

the converter connected to operate as a flyback type converter.

5. A switching mode power converter, comprising:

a power transformer including a magnetizing inductance requiring periodic recycling;

a first power stage for converting a DC input into a periodic pulsed voltage applied to a primary winding of the transformer, including:

a clamping circuit for limiting a voltage of the transformer during the periodic recycling at a substantially constant amplitude and extending the voltage duration to maintain a constant voltage for substantially an entire extent of periodic recycling;

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a second power stage for rectifying an output of a secondary winding of the transformer and applying it to a load to be energized, including:

a synchronous rectifier including a first rectifying device with a control gate connected to be responsive to a signal across the secondary winding such that the synchronous rectification device conducts a load current during the periodic recycling when the clamping circuit is active, and

a second rectifying device connected for enabling conduction of the load current when the first rectifying device is nonconducting.

6. A switching mode power converter as claimed in claim

5, further comprising:

the second rectifying device comprises a diode.

7. A switching mode power converter as claimed in claim

5, further comprising:

the second rectifying device comprises a rectifying device with a control gate connected to be responsive to a signal of the secondary winding.

8. A switching mode power converter as claimed in claim

6 or 7, further comprising:

the secondary winding tapped and separated into first and second winding segments, and the first rectifying device is connected to the first winding segment and the second rectifying device is connected to the second winding segment.

9. A switching mode power converter as claimed in claim

6 or 7, further comprising:

the converter connected to operate as a forward type converter.

10. A switching mode power converter as claimed in claim 6 or 7, further comprising:

the converter connected to operate as a flyback type converter.

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